

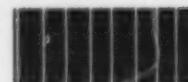


DEVELOPMENT AND TESTING OF A LOCOMOTIVE FUEL SAVER SYSTEM

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Prepared for
TRANSPORTATION DEVELOPMENT CENTRE
POLICY AND COORDINATION GROUP

TRANSPORT CANADA

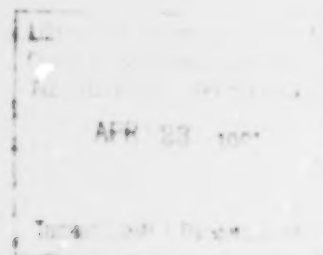
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DSL Dynamic Sciences Limited



DECEMBER 1990

472094

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**DEVELOPMENT AND TESTING OF A
LOCOMOTIVE FUEL SAVER
SYSTEM**

FINAL REPORT

**Prepared for
TRANSPORTATION DEVELOPMENT CENTRE
POLICY AND COORDINATION GROUP**

TRANSPORT CANADA

DECEMBER 1990

The contents of this report reflect the views of the authors and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

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16. Abstract This is the final report on a project which provided partial assistance in the development, implementation, and field testing of the Duty Cycle Controller (DCC). The purpose of the DCC is to conserve locomotive fuel by automatically shutting down locomotive engines when they are not needed. The system may be used in single-unit or multiple-unit operation on both manned and unattended locomotives. Results of early field experience on five preproduction prototypes allowed design improvements to be defined and implemented. A subsequent four month field test using thirty-five production units provided the necessary data to allow the identification of a minor design improvement and the estimation of fuel savings possible. Conservative estimates for SD40-2 locomotives in a typical Canadian climate are on the order of 29000 l per locomotive per annum. In the case of one major Canadian railway, this would correspond to a savings of approximately 4% of the total cost of fuel.					
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16. Résumé Ceci est le rapport final d'un projet qui a fourni une aide partielle à un programme de développement, à la réalisation et aux essais sur le terrain, du «Duty Cycle Controller» (DCC). Le but du DCC est d'économiser le carburant diesel en arrêtant automatiquement les moteurs des locomotives lorsqu'ils ne sont pas requis de fonctionner. Le système peut être utilisé sur des locomotives opérant en configuration simple ou multiple, aussi bien sur les locomotives de contrôle que sur celles qui sont contrôlées. Les résultats des premières expériences sur le terrain faites sur cinq prototypes de préproduction ont permis de définir les améliorations devant être apportées au design et de les réaliser. Un test subséquent sur le terrain, d'une durée de quatre mois et utilisant trente-cinq unités de production, a fourni les données nécessaires qui ont permis l'identification d'une amélioration mineure du système ainsi qu'une estimation des économies de carburant possibles. Des estimations prudentes pour les locomotives SD40-2 dans un climat typiquement canadien sont de l'ordre de 29 000 litres par locomotive, par année. Dans le cas d'une société ferroviaire canadienne d'importance, cela correspondrait à des économies d'approximativement 4 p.100 du coût total de carburant.				
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Summary

Railways spend more operating funds on fuel than on any other purchased item. Thus, fuel conservation is of considerable interest and value.

DSL Dynamic Sciences Limited (DSL) has developed the Duty Cycle Controller (DCC), a microprocessor-based product which can easily be installed, in its present form, on SD40-2 type locomotives. The DCC system conserves fuel by automatically shutting down locomotives when they are not needed. When either the engine temperature or the coolant drain temperature drops below a preset limit, the engine is automatically restarted and runs in throttle 4 until the engine temperature exceeds a second preset limit. This approach avoids the risks and impracticalities of manual shutdown and restart, and has been shown, by field tests, to save significant amounts of fuel.

The DCC can be used in main-line single-unit or multiple-unit operations when locomotives are operating at less than full power, when transferring isolated idling locomotives, and when locomotives are otherwise idle, even when unmanned.

The project described herein covers the partial development, installation, and field testing of the DCC.

Five preproduction prototypes were developed from a bench prototype and were installed on locomotives belonging to the Quebec North Shore and Labrador Railway (QNS&L). This early field experience allowed the production design to be finalized and implemented.

Thirty-five production units were then installed on QNS&L locomotives and a four-month test was performed. The results of this test allowed the identification of desirable improvements to the system, and also allowed the determination of relationships between fuel savings and ambient temperature, and between system utilization and ambient temperature.

Based on these relationships, it was then possible to produce a conservative estimate of annual savings that can be expected per locomotive. These estimates were produced both for Sept-Iles (the QNS&L terminal) and for Montreal. In spite of quite different statistical temperature profiles for these two locations, the predicted annual savings per locomotive were remarkably similar, about 29000 l per year per locomotive. In the case of one major Canadian railway, this would correspond to a 4% reduction in fuel cost.

The overall objective of developing a cost-effective product to allow Canadian railways to conserve fuel has been met; the results of the study are extremely encouraging.

Sommaire

Les sociétés ferroviaires dépensent plus de fonds d'exploitation en carburant diésel que sur tout autre achat de matériel. En tant que telle, la conservation de carburant est d'un intérêt et d'une utilité considérables.

DSL Sciences Dynamiques Limitée (DSL) a développé le «Duty Cycle Controller» (DCC), un produit à base de microprocesseur qui peut facilement être installé, dans sa présentation actuelle, sur les locomotives de modèles SD40-2. Le système DCC conserve le carburant en arrêtant automatiquement le moteur de la locomotive lorsqu'il n'est pas requis d'être en marche. Que ce soit lorsque la température du moteur ou de la vidange d'eau baisse au dessous d'une limite pré-établie, le moteur est automatiquement remis en marche et fonctionne avec le levier d'utilisation en position 4 jusqu'à ce que la température du moteur dépasse une autre limite pré-établie. Cette approche évite les risques et les inconvénients de l'arrêt et du redémarrage manuels, et a démontré, au cours des tests faits sur le terrain, une économie appréciable de carburant.

Le DCC peut être employé sur des locomotives fonctionnant en configuration simple ou multiple, sur la voie principale, lorsqu'ils sont conduites à une puissance inférieure à la puissance maximum; quand des locomotives fonctionnant au ralenti sont prises en remorque, et au moment où elles sont au ralenti, même dans le cas où elles ne sont pas sous le contrôle d'un opérateur.

Ce projet couvre une partie du programme de développement, de l'installation et des tests sur le terrain du DCC.

Cinq prototypes de préproduction ont été développés à partir d'un prototype de laboratoire et ont été installés sur des locomotives appartenant au Quebec North Shore and Labrador Railway (QNS&L). Cette première expérience a permis au modèle de production d'être complété et exécuté.

Trente-cinq unités de production ont alors été installées sur des locomotives de QNS&L et un test d'une durée de quatre mois a été fait. Les résultats de ce test ont permis l'identification des améliorations devant être apportées au système, et ont aussi permis de déterminer les rapports entre les économies de carburant et la température ambiante, ainsi qu'entre l'utilisation du système et la température ambiante.

En se basant sur ces rapports, il a alors été possible d'en arriver à une estimation prudente des économies de carburant escomptées par locomotive. Ces estimations ont été produites pour Sept-Iles (le terminus de QNS&L) et pour Montréal. En dépit des profils statistiques de températures assez différents pour ces deux endroits,

les économies de carburant prévues par locomotive étaient remarquablement similaires, approximativement 29 000 litres par année par locomotive. Dans le cas d'une société ferroviaire canadienne d'importance, cela correspondrait à une réduction des coûts de carburant de 4 p.100.

L'objectif d'ensemble du développement d'un produit rentable pour permettre aux sociétés ferroviaires canadiennes de conserver le carburant a été rencontré; les résultats de cette étude sont extrêmement encourageants.

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1. INTRODUCTION

1.1 Background

Fuel conservation is an area of considerable interest for Canadian railways. This project provided partial assistance in the prototyping, fabrication, installation, and testing of thirty-five units of a system which conserves fuel by automatically shutting down locomotive engines when they are not needed.

Unnecessary operation occurs in three instances:

- o in main-line multiple-unit operation, with locomotives operating under less than full power;
- o in transferring a power unit with the unit isolated and the engine idling; and
- o in "shunting" engines when idling, usually while on stand-by on a yard track.

Manual shut-down requires a conscious decision both to shut down and to restart. If locomotives are allowed to cool below certain critical limits, an existing safety feature automatically drains the engine coolant to prevent the possibility of damage due to freezing. Once drained, it requires a major effort to return the unit to operating condition. Consequently, normal current practice in cold weather is to keep units idling with a resultant waste of fuel.

DSL Dynamic Sciences Limited (DSL) has developed a microprocessor-based control system which has been shown to be able to reduce overall fuel consumption for SD40-2 locomotives by approximately 4%. The system allows the locomotive engine to be completely shut down when the locomotive is not required for work, whether the unit is stationary or is in a multiple unit consist in mainline service. The system also continually monitors the status of engine control equipment and sets alarms in the event of failure of critical components. The system has been designed for easy retrofit to any SD40-2 type locomotive.

1.2 Prior to this Project

Prior to the project discussed in this report:

- o QNS&L had devised the basic principle and had successfully demonstrated proof of concept on one SD40-2 locomotive using a manually operated lashed-up relay-logic-based experimental system.
- o QNS&L transferred their knowledge to DSL so that DSL could develop a usable product.
- o DSL developed an initial design and progressed both the hardware and the software to the point of having a working bench prototype.
- o QNS&L committed to the purchase of thirty-five production units.

- o DSL made a proposal to TDC for the development of five preproduction prototypes to be installed and field tested on QNS&L locomotives.

1.3 This Project

On the basis of DSL's progress leading to a successful bench prototype, and the clear interest from QNS&L, TDC awarded DSL a contract to perform the proposed work.

1.3.1 Objectives

The overall objective was to reduce fuel consumption through more efficient management of locomotives.

Project objectives were two-fold:

- To provide a means for railways to save a significant amount of fuel, through the reduction in locomotive idling time, by developing a locomotive fuel saving control system which could automatically stop and start a locomotive engine.
- To verify, through field tests, the actual fuel savings and provide performance data necessary to support manufacturing and marketing of a final device.

These objectives have been met.

1.3.2 Scope of the Project

Work done during the period of the project included both work within the scope of the TDC project and related but separately funded work as follows:

1. Testing of the bench prototype.
2. Development of the preproduction prototype design based on the bench prototype.
3. Construction and installation of a first preproduction prototype on QNS&L locomotive #241.
4. Construction and installation of the balance of the 5 preproduction prototypes.
5. Development of the production unit design based on the preproduction prototype experience.
6. Manufacturing and installation of the thirty-five production units (including replacement of the five preproduction units) on QNS&L locomotives.
7. Monitoring of the in-service performance of all 35 production units in order to identify and rectify any application problems and to generate statistics on achievable fuel savings.
8. Analysis of the results of the tests including prediction of what fuel savings may reasonably be expected in the Canadian climate.

2. SYSTEM DESCRIPTION

2.1 Functional Description

2.1.1 Primary Function

The primary function of the DCC is to save fuel by shutting down the locomotive engine when not required for work; that is, when it would normally be in idle. If it is not needed, and if the engine temperature exceeds 55C, the engine is shut down. When the temperature drops below 38C, the engine is restarted and operates in throttle 4 until the temperature again reaches 55C. In this way, engine temperature is maintained at a safe level and fuel is conserved.

2.1.2 Modes of Operation

The DCC has three basic modes:

1. Independent Unit Fuel Saving Mode

In this mode the system controls the response of a single locomotive which is not in use; i.e., one which is on standby or is being transferred.

2. Multiple Unit Fuel Saving Mode

In this mode, the system removes unneeded power in a consist of multiple locomotives by selectively shutting down and cycling the lead locomotive and/or groups of one or more trailing locomotives.

3. Normal Mode

In this mode, the system is disabled. The locomotives function as they would if the DCC were not installed.

2.1.3 Other Functions and Features

Secondary and support functions include: cold weather protection, starter motor protection, safety and ease of operation, self-diagnostics, and a cab start feature.

2.2 System Hardware

2.2.1 Overview

The system consists of a Main Control Unit (MCU), a System Control Panel, a Consist Control Panel, and various sensors and actuators as illustrated in Figure 2-1. Figure 2-2 shows the major system components and their approximate locations on the locomotive.

2.2.2 Description of Equipment

The following is a list of the most important components with a short description of each.

Main Control Unit (MCU)

The Main Control Unit, mounted on the inside of the electrical cabinet door, contains the process control and interface circuitry. This

is connected to various points in the locomotive control and protection circuits. All connections between the Controller and the locomotive circuits are made through two detachable plugs on the bottom of the MCU. The system can be switched off by tripping the circuit breaker on top of this unit.

System Control Panel (SCP)

The System Control Panel is shown in Figure 2-3. It is mounted on the electrical cabinet door and allows the operator to select/determine the status of the locomotive for fuel saving operations. The panel also indicates modes of operation and fault conditions.

All controls are on the left half of the System Control Panel, and consist of two rotary switches and a pushbutton. The left switch is the main control and has six positions as follows:

- Lead:

This setting is used to identify the locomotive as the controlling (lead) unit in a multiple-unit consist.

- Trail:

This setting is used, in conjunction with the rotary switch to the right, to identify the locomotive as being a controlled (trail) unit in a multiple-unit consist. The right switch is set on trailing locomotives to identify them as belonging to one of six "groups" of trailing locomotives (only groups one and two are implemented in the QNS&L installation).

- Independent Unit Fuel Saving:

This setting is used to put this single locomotive into Fuel Saving mode.

- Start:

This setting is used, in conjunction with the pushbutton in the lower right corner of the left half of the panel, to start the engine.

- Normal:

This setting disables the DCC on this unit.

- Self-Test:

This setting is used for check-out and maintenance purposes.

Consist Control Panel (CCP)

The CCP is the small box illustrated at the top left of Figure 2-2. It contains three push-button switches and is normally mounted on the control stand. The switches are used to remotely control fuel saving operations on trailing locomotives in a multiple unit consist.

The controls on this box are only active in the lead locomotive of a multiple-unit consist. There are three two-position pushbuttons as follows:

- Lead:

When depressed, places the lead locomotive in Fuel Saving Mode.

- Trail 1:

When depressed, places the trailing locomotives in Group 1 into Fuel Saving Mode.

- Trail 2:

When depressed, places the trailing locomotives in Group 2 into Fuel Saving Mode.

Engine Coolant Temperature Sensor

A sensor is installed in a thermowell on the right side water pump discharge elbow and is used by the system to determine the temperature of the engine coolant. This is the primary controlling device that determines when to start and stop the locomotive engine. Temperature limits are set by software in the MCU to 38C for restarts and 55C for stops.

Water Drain Temperature Sensor

A temperature switch is located at the coldest point in the engine cooling system and is used as a secondary engine start controlling device. On QNS&L locomotives this switch is part of a protection subsystem that would normally cause the dumping of the water if the temperature at this point drops below the switch setting of 4.5C. The original arrangement has been modified with the inclusion of a time delay and increasing of the setting to 11C to allow restarting of the engine well before the critical temperature is reached.

Engine RPM Sensor

A magnetic transducer senses the passage of the flywheel teeth. Its output is used by the MCU to monitor engine rotation at all times. Abnormal speed of rotation results in the triggering of an alarm.

It plays a particularly important role at cranking time in detecting starter motor overload. An algorithm estimates heat accumulation in the starter motor rotor based on speed of rotation. If the preset limit is exceeded, cranking is immediately aborted. This feature prevents abuse of the starter motor when the cab start function is used.

Other Sensors

As part of locomotive protection and safety of operation, the states of the Emergency Fuel Cut-Off Switch, Low Oil Switch, Auxiliary Generator, and Automatic Drain Valve are sensed and monitored.

Train Lines

Two spare Train Lines are required to allow fuel saving operation in a multiple locomotive consist. These lines are driven from the DCC in the Lead Unit and sensed by the DCC's in Trail Units. Trail Units are set to belong to one of two possible "groups" of locomotives at set-up time. In QNS&L's case, the lines can be linked to remote units via the Locotrol system.

When the system is set up for multiple unit operation, the engineman, using the Consist Control Panel, can off-load either or both of the two groups of Trail locomotives. The selected locomotives will then enter the fuel saving mode and will cycle on and off individually as a function of temperature.

Alarms

For safety of operation, two alarm buzzers are provided with the system, one located on the System Control Panel in the cab and the second in the engine room. The buzzers are activated before cranking to warn personnel that the engine is about to be started.

The Train Line Alarm and Signal Light are interfaced and activated in case of a system malfunction to call for assistance. The Signal Light is located on the top of the locomotive cab and is visible from large distances.

Isolation Switch Actuator

Operation of the Isolation Switch on remote or trail locomotives in a Multiple Unit Consist is automated by means of a motorized actuator attached directly to the shaft of the switch. The actuator is driven only when a locomotive designated as a "Trail" unit is entering or exiting Start-Stop Cycling Mode as a result of a command transmitted through the trainline. Manual operation of the switch is not affected by the presence of the actuator.

Low Water Reset Actuator

To overcome the possibility of a false tripping of the low water protection device during cranking, a solenoid-driven actuator mounted over the Low Water Reset push-button is activated twice for 5 seconds about 10 and 20 seconds after the engine has begun to run on its own. Manual operation of the reset button is not affected by the presence of the actuator.

Fuel Prime / Engine Start (FP/ES) Module

This solid-state relay module provides the MCU with an interface to the locomotive's Fuel Pump and Starter Motor control circuits. It allows the automatic start function. Once installed it becomes a permanent part of the locomotive electrical circuit. The manual FP/ES switch is interfaced to the module for normal operation.

Engine Governor

In order for the System to be able to automatically run the engine at Idle and at Throttle 4, and to stop the engine, an interface is provided to permit the activation of Governor solenoids A, C, and D.

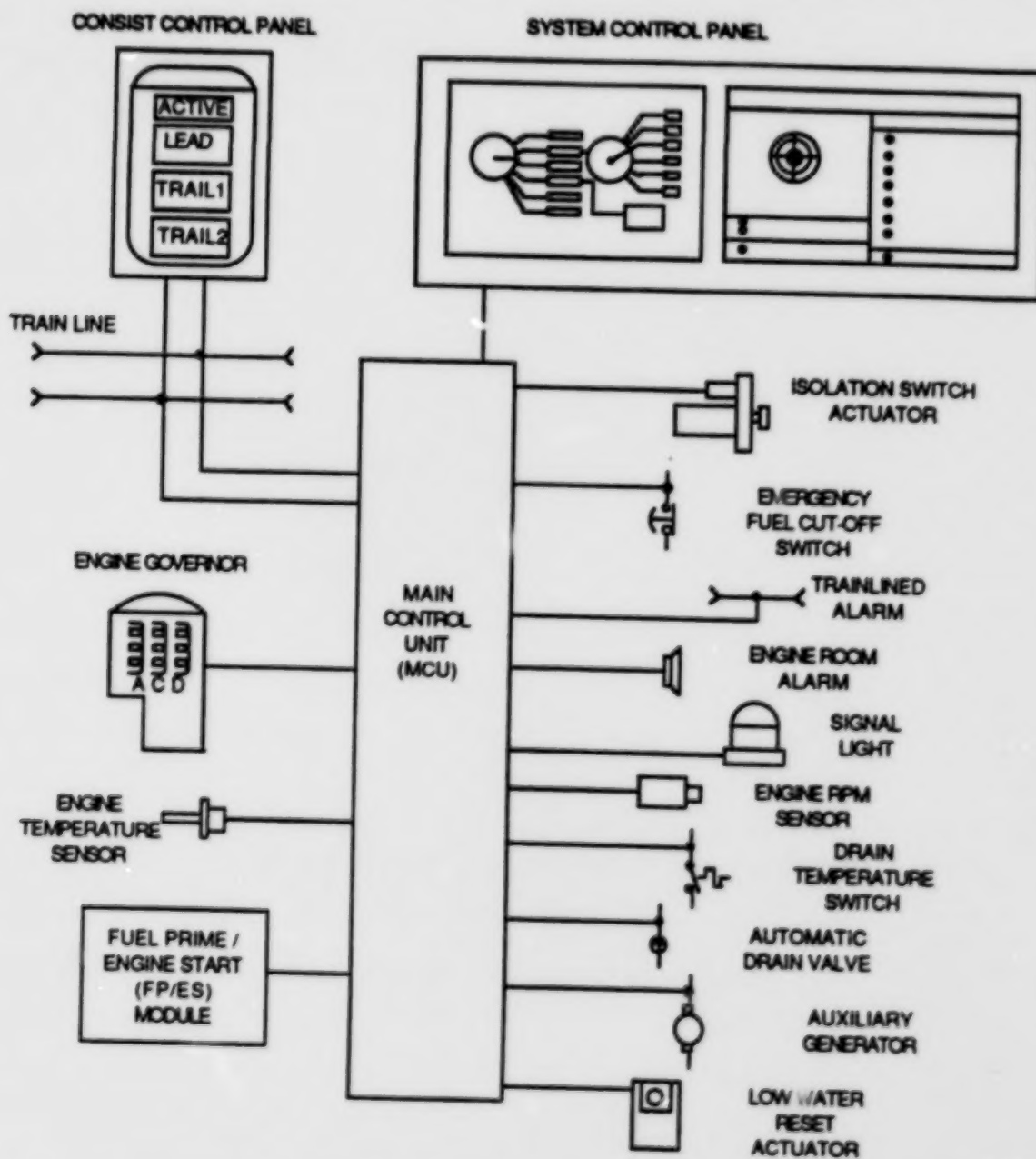
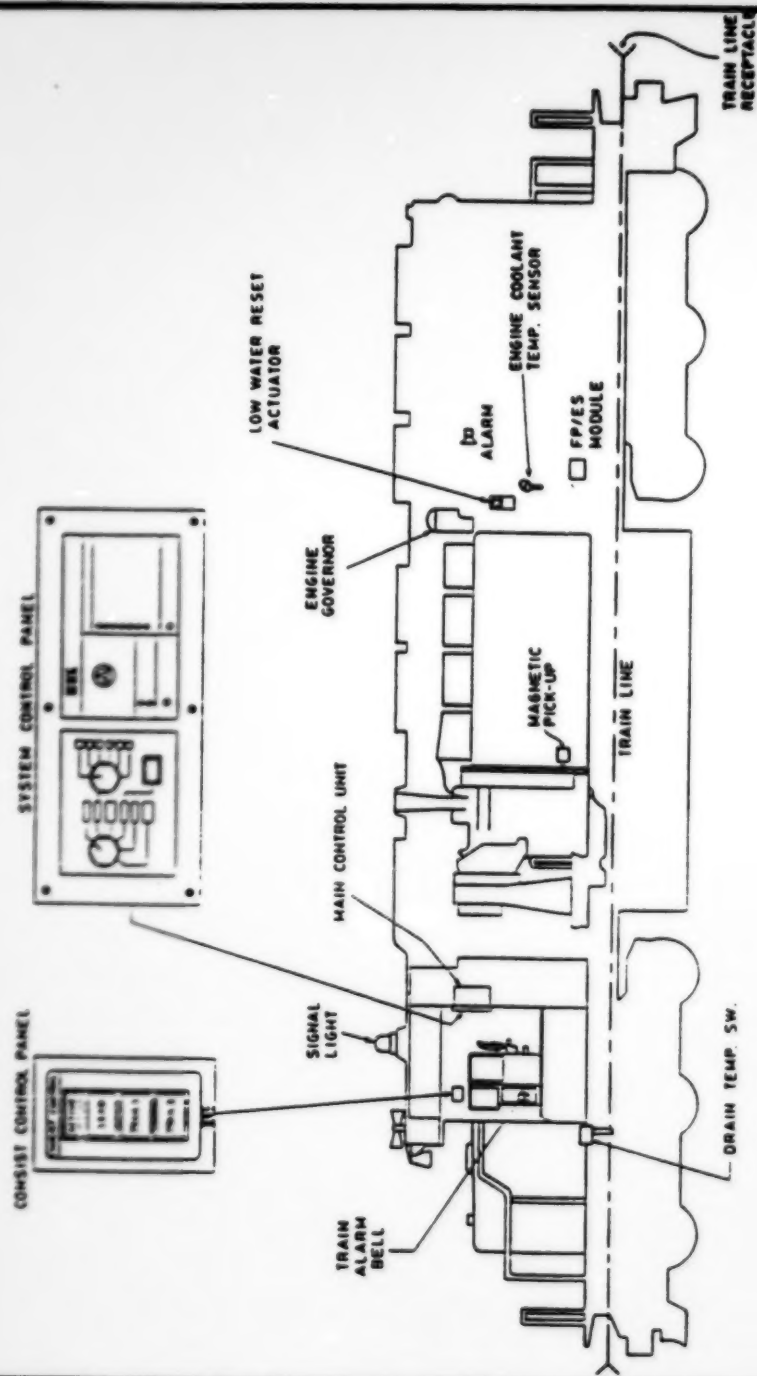


Figure 2-1
SYSTEM BLOCK DIAGRAM

DSL



SYSTEM LAYOUT

Figure 2-2

LOCATION OF MAJOR SYSTEM COMPONENTS

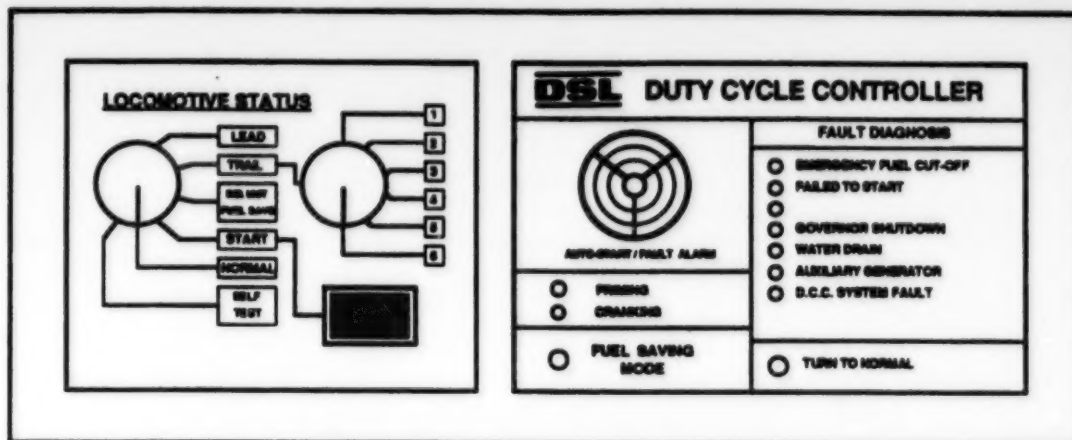


Figure 2-3
SYSTEM CONTROL PANEL

3. DEMONSTRATION TEST

The objectives of the demonstration test were to verify the expected performance of the unit and to identify any problems of reliability or maintenance which might arise over time.

3.1 Test Methodology

Because of the high cost and difficulty in measuring fuel consumption using a fuelfmeter, it was decided to measure savings indirectly by recording time parameters. Software was developed to accumulate and log operating parameters within the DCC memory.

This software monitors the operation of the system and accumulates events into counters. A series of timers accumulates the time spent in the different modes or performing certain operations such as running the engine at throttle 4. Another series of counters was used to accumulate the occurrence of events such as engine start, activation of the low oil switch, etc.

The data were recorded into the system memory and downloaded at varying time intervals, typically a few days, by QNS&L engineering personnel. The data were extracted at the locomotive shop using a portable printer via an RS-232C port located on the MCU. Printed data were manually transferred to a log sheet. Appendix 1 shows the log sheet that was used to record the readings; descriptive information about each parameter is also provided. The "recorded temperature" value is the temperature at the time of extraction.

Aspects of reliability and maintenance were addressed by collecting regular shop maintenance reports. Emphasis was on items about which concerns had been raised such as batteries and starter motors.

3.2 Collected Data

Data were entered on a spreadsheet for further processing, with each individual log sheet becoming a single record, thus providing a first level of data compression. Part of a sample spreadsheet with the records sorted by locomotive and by date of extraction is provided in Appendix 2.

The following table summarizes the extent of the compiled test data.

Number of extractions	501
Period covered	Dec. 15, 1988 to Apr. 15, 1989
Average Temperature over period	-12C
Number of locomotives	33
Hours in Independent Fuel Saving mode	6557
Total number of automatic start cycles	2500
Hours in Lead Fuel Saving mode	None
Hours in Trail Fuel Saving mode	None
Hours in Throttle 4	450

TABLE 3-1 - TEST DATA STATISTICS

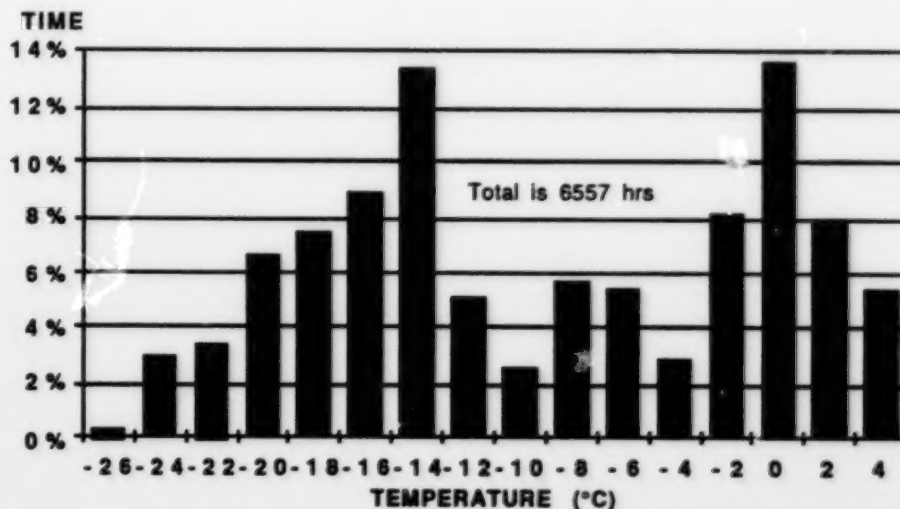
The first remark that can be made is to note that the system has been used exclusively in Independent Fuel Saving Mode. No advantage was taken from using the system on the road. The main reason for this is that train crew personnel had not yet been trained to use the DCC. The system was used and operated only by shop personnel under supervision of the QNS&L Engineering department. No data were collected outside the shop area.

Figure 3-1 shows the distribution of recorded Fuel Saving mode hours as a function of ambient temperature.

The two peaks roughly correspond to the temperature profile for the period; average temperatures were about -15°C for December, January, and February and 0°C for March. One can see from this that about 50% of the system utilization hours were at temperatures below -10°C. Temperatures in Sept-Îles (the city at the southern end of the QNS&L line), for the test period are given in Appendix 3.

Figure 3-2 is interesting in that it shows wide variations in system utilization from locomotive to locomotive. This can be explained by different factors. Some of the locomotives (e.g., numbers 3, 10, 14, and 15) were taken out of service at some point before and/or during the test period. The other main reason is that system installations were gradually completed during the test period.

Figure 3-3 shows the utilization of the system by month over the test period. It clearly illustrates the gradual increase just mentioned.



Note: There are no data below -26°C or above +4°C.

Figure 3-1

DISTRIBUTION OF FUEL SAVING HOURS VS TEMPERATURE
OVER 120-DAY TEST PERIOD

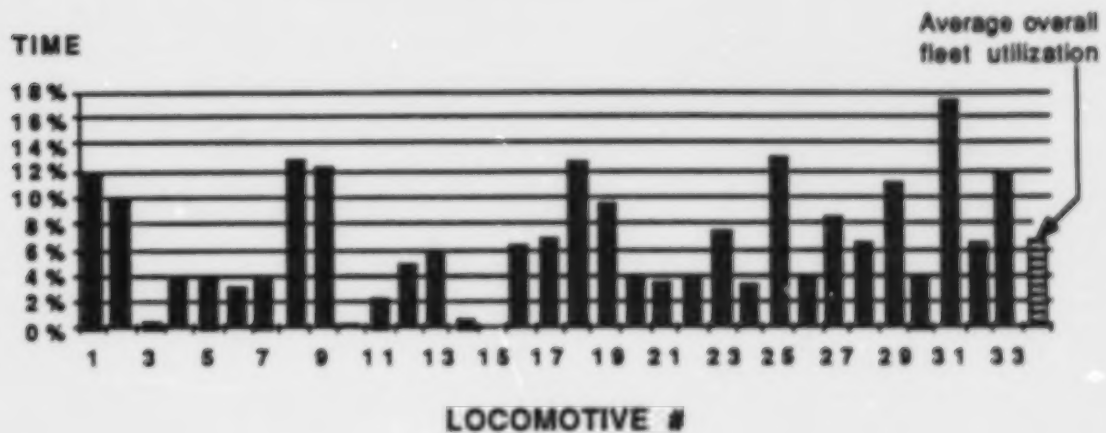


Figure 3-2

DCC UTILIZATION BY LOCOMOTIVE
OVER 120-DAY TEST PERIOD

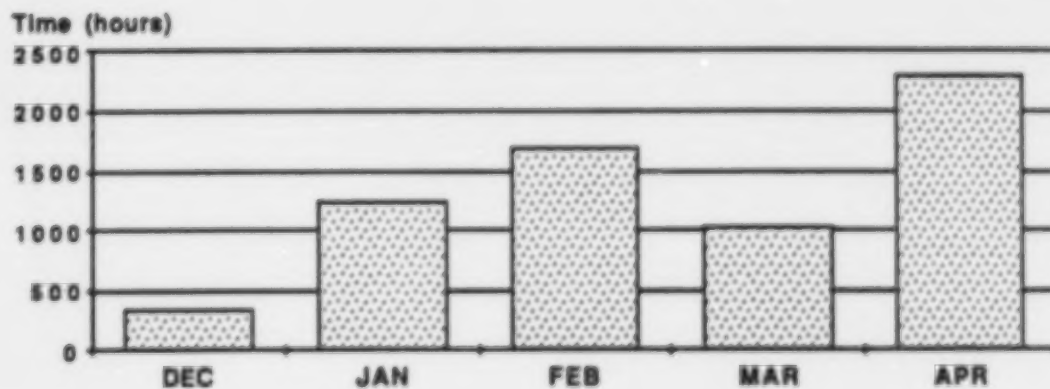


Figure 3-3

TOTAL DCC UTILIZATION OVER TEST PERIOD

3.3 Fuel Saved

Savings were calculated from the recorded time parameters. Fuel is saved when an engine is stopped. The savings is calculated as the amount of fuel that the engine would normally have consumed if it had been running at low-idle, less that consumed when the engine is restarted to maintain engine temperature.

Figure 3-4 presents a typical cycle timing along with the formula used to calculate savings.

Using this scheme, savings were calculated for each individual locomotive as shown in Figure 3-5.

Figure 3-6 shows the distribution of savings with respect to temperature. The shape of this curve is very similar to that of Figure 3-1 above except that there is a relative attenuation in the magnitude of the savings as temperature decreases. Savings depend not only on time spent in fuel saving mode but also on ambient temperature. Here also the shape of the curve is more representative of the average ambient temperature than of anything else. It also demonstrates that a significant portion of the fuel saved over the test period was saved at relatively low temperatures.

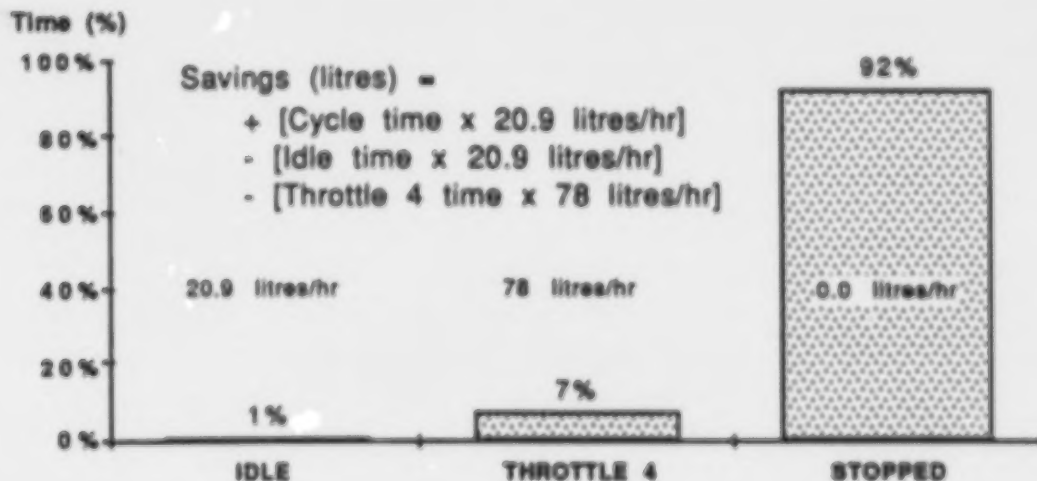


Figure 3-4

TYPICAL CYCLE TIMING AND SAVINGS

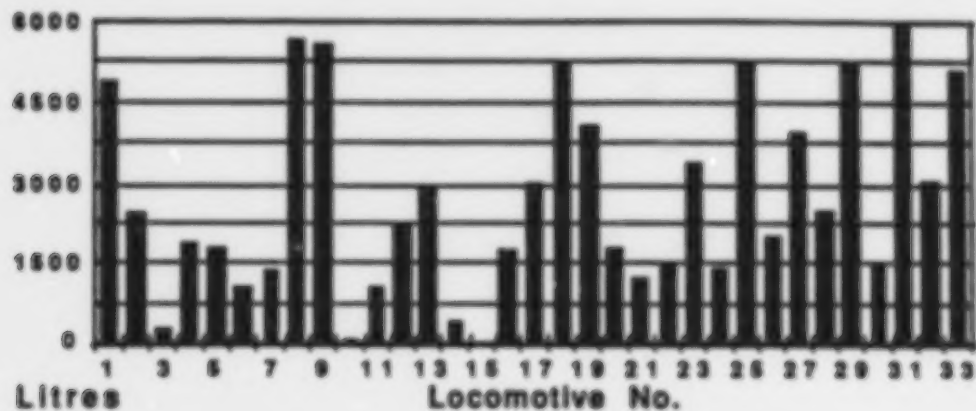


Figure 3-5
SAVINGS, BY LOCOMOTIVE, OVER THE TEST PERIOD

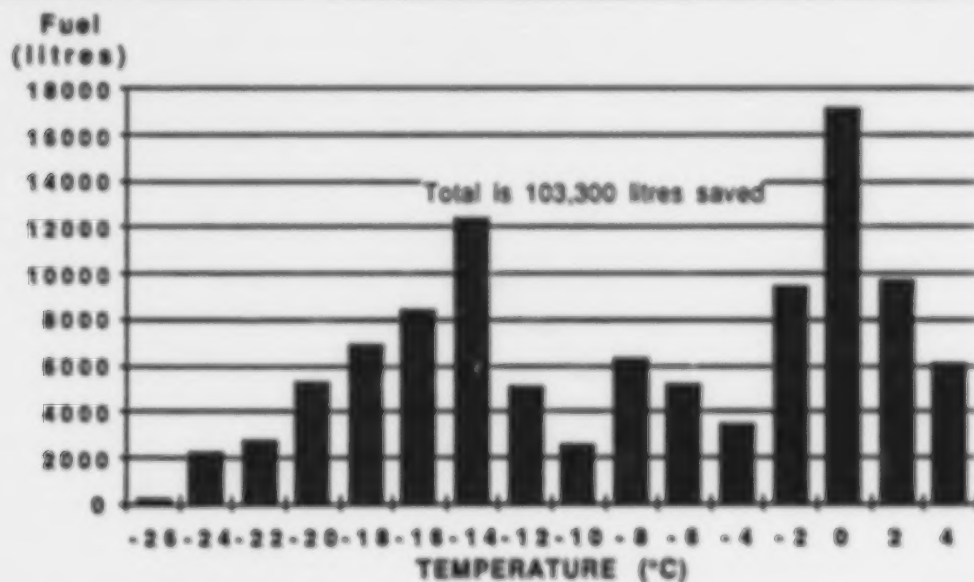


Figure 3-6
DISTRIBUTION OF SAVINGS AS A FUNCTION
OF TEMPERATURE OVER THE TEST PERIOD

3.4 System Performance

3.4.1 "Effectiveness"

The quantitative measure of system performance is termed the "Effectiveness".

The ideal would be to save the total amount of fuel that is normally consumed by the locomotive when idling. This would result in an Effectiveness of 100%, where Effectiveness is defined as:

$$\text{Effectiveness} = \frac{\text{Net Fuel Saved}}{F_{\text{max}}} \times 100\%$$

where:

F_{max} = amount of fuel that would have been used by the locomotive in low idle if the DCC were not in use.

As expected, the test results show that Effectiveness is a function of ambient temperature. Effectiveness values were calculated for all readings. The results were grouped according to temperature and the average Effectiveness was calculated at intervals of 2 Celsius degrees. Results are plotted in Figure 3-7 using white diamonds. The straight line through the black diamonds was determined by the method of least squares. This is used later in the calculation of projected savings.

Note that for temperatures above approximately 0C the Effectiveness exceeds 90% making the system very attractive at those temperatures. Less interesting are the savings below -20C, their magnitude not much beyond 50%.

3.4.2 Other Findings of Note

A very interesting finding is derived from plotting Figure 3-8, the number of automatic starts as a function of temperature. One has only to compare this graph to Figure 3-6 to immediately see the point. Even though the achieved fuel economy is larger at temperatures around 0C, the number of starts is much larger (by a factor of about 3) at temperatures around -15C. This curve is not normalized; its shape is highly representative of temperature distribution during the test.

Figure 3-9 represents the same results expressed in a normalized manner. Values of cycle time, the inverse of the number of starts, were averaged for each range of 2 Celsius degrees and plotted. What is striking in this plot is the knee point at around -2C where cycle time abruptly jumps from 2 hours to almost 6 hours over a temperature difference of only about 5 Celsius degrees. That can be explained by a finding evident from Figure 3-8; it's at about this same temperature that the source of the start command is gradually switching from the drain sensor to the engine sensor.

In other words, the system is switching from a drain temperature regulator mode to an engine temperature regulator mode. Because of the differences in thermal mass, it takes much more time for the engine to cool down than for the drain and cab heater system. Higher savings with a much lower number of automatic starts may therefore be expected for locomotives equipped with electric cab heaters.

The time spent per cycle running the engine at throttle 4 is fairly constant over temperature as demonstrated in Figure 3-10. A slight tendency may be seen towards a longer time with decreasing temperature as one would expect.

3.5 Installation and Training

DSL prepared Installation Instructions on the basis of which a two day course was given to QNS&L shop personnel. On this foundation, they were able to install the units with only minimal support from DSL.

The system was designed to be easy to install, and this proved to be the case; installation required, on average, two men for one working day per locomotive.

As regards training of the users, a User Manual was prepared for the locomotive engineers. Training of locomotive engineers was done in a classroom setting and was completed in approximately one day.

3.6 System Reliability and Maintainability

Due to a lack of continuity of personnel at QNS&L, quantitative data regarding maintenance and reliability are not available.

However, in the almost two years since the systems were installed, very few have been returned to DSL. In all cases, failures have been due to minor design problems which have since been rectified.

Best available information indicates that, on the basis of these 35 units, reliability is excellent and there is essentially no need for maintenance.

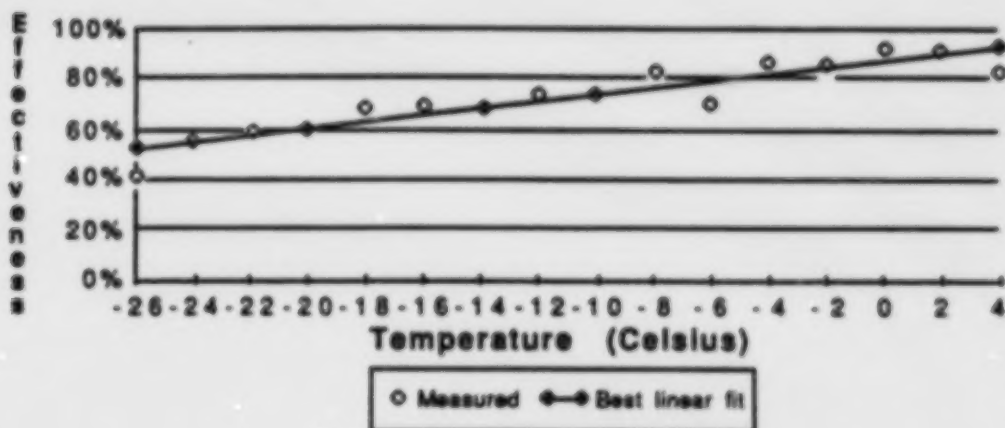


Figure 3-7

EFFECTIVENESS

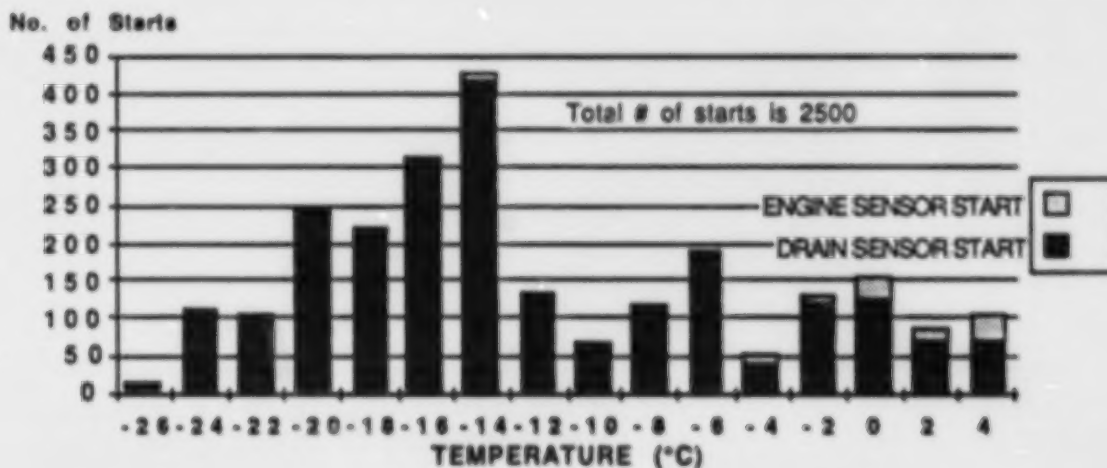


Figure 3-8

TOTAL # OF STARTS VS TEMPERATURE

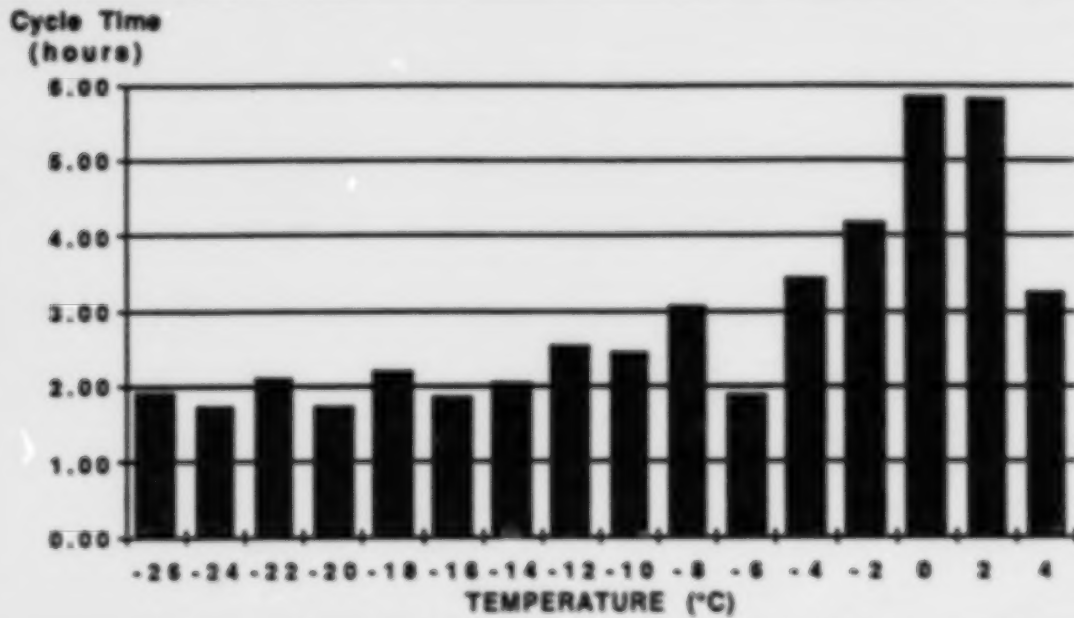


Figure 3-9

CYCLE TIME VS AMBIENT TEMPERATURE

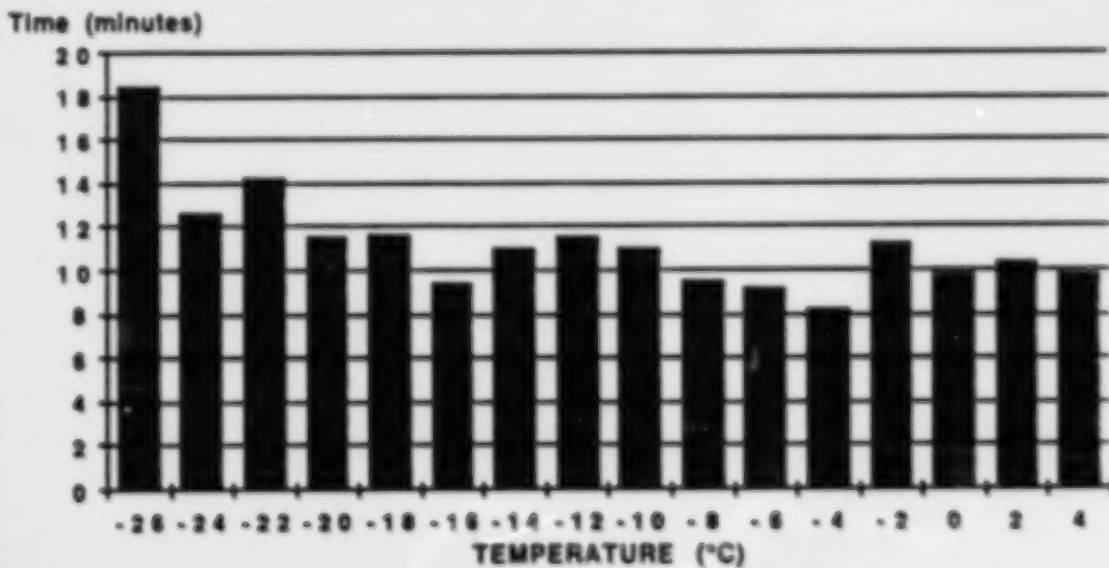


Figure 3-10

AVERAGE TIME PER CYCLE VS AMBIENT TEMPERATURE

4. PREDICTED SAVINGS

4.1 Introduction

The previous chapter presents the results of the four-month demonstration test. The next logical step is to derive a conservative estimate of annual savings per locomotive that may reasonably be expected over the long term.

Since data were not available to establish performance parameters for on-the-road operation (i.e., off-loading of excess power), this feature is not taken into consideration in what follows. One can only predict that the actual savings will be larger than those estimated below when this other mode is also used.

4.2 System Utilization

Looking first at DCC utilization during the test period to see what portion of the total time the DCC was used, Figure 4-1 shows that the system was used for only a small fraction of the available isolated idling hours. Overall, the locomotives were only under DCC control 6.6% of the total time. During another 36.4% of the total time, they could have been and were not. That is, they could have been under DCC control 43% of the total test time. The reasons for this low actual utilization are two-fold:

- (1) Installations were proceeding during the test period. Early utilization was low because many of the units had not yet been installed.
- (2) More importantly, the units supplied to QNS&L did not cause idling locomotives to enter Fuel Saving mode automatically. The major reason for this was the lack of prior experience. The test period did, however, supply that missing experience and, as described in section 5 of this report, the design should be modified so that future models will automatically put an idle locomotive into Fuel Saving Mode.

On the basis that this improvement will be implemented on all future DCCs, the following projections assume a utilization factor of 40%; this is conservative considering the just-mentioned improvements to the system.

The projections assume a utilization factor that is dependent on ambient temperature. Average monthly temperatures were used to select the appropriate utilization factor from the graph shown in Figure 15.

It was decided to make the projections assuming that Fuel Saving mode would be used only when ambient temperature is between -10C and +10C. The basis for this is that savings at low temperatures are less and the number of starts is much higher. Therefore, to stay on the conservative and safe side, operation below -10C has been eliminated. This provides higher system reliability and safety without sacrificing too much on savings. For temperatures above +10C, engines can be shut down safely without the system; those temperatures are therefore also eliminated.

The curve in Figure 4-2 was derived from an ideal square window going from -10C to +10C. By using daily average temperatures for every month it can be seen that at, say, -10C, the system will be used, on average, during half of the month, giving a utilization factor of 20% (50% x 40%). The slope around this point has been selected based on daily minimum and maximum temperature deviations from the norm, roughly +/- 5 Celsius degrees throughout the year.

Utilization factors are determined from normal temperatures as found in the Environment Canada publication "Canadian Climate Normals, 1951-1980".

4.3 Predicted Savings

Given the assumptions explained above, it remains to determine the predicted savings per locomotive per annum.

This is done by first calculating monthly savings and then by summing these values over the twelve months of the year.

4.3.1 Predicting Monthly Savings

Monthly savings are calculated as follows:

$$\text{Savings} = \text{Hours} \times 20.9 \text{ litres/hr} \times \text{EFF} \times \text{UF}$$

Where:

Hours = Average number of hours per month;

EFF = System Effectiveness at normal temperature for the month as established from Figure 3-7;

UF = Utilization factor at normal temperature for the month obtained from Figure 4-2.

4.3.2 Predicted Annual Savings

The results of calculations for Sept-Iles and Montreal are shown in Figures 4-3 and 4-4 respectively. The columns represent the extrapolated savings in dollars per locomotive per month. The temperature profile is plotted on the Celsius scale shown on the left side of the graphs; litre of fuel saved per locomotive, per month, is shown on the scale on the right.

4.3.3 Predicted Savings Elsewhere in Canada

It is interesting to note that although the temperature profiles for Sept-Iles and for Montreal are quite different, the yearly savings per locomotive are very similar; 27,200 litres in Montreal compared to 31,500 litres for Sept-Iles.

From this, one might hypothesize that the number of days having a mean temperature between -10C and +10C is very similar in most parts of Canada.

Project resources did not permit this hypothesis to be investigated, and it has not been verified. Nonetheless, if one assumes this to be the case, a conservative estimate of annual savings is approximately 29,000 litres per locomotive.

In the case of one major Canadian railway, the annual fuel used (in 1990) was approximately 850 million litres for 1230 locomotives, about 9% of which are not operational on average. This corresponds to an annual consumption of 759,400 litres per operating locomotive. On this basis a savings of 29,000 litres per year corresponds to a 4% reduction in total fuel costs.

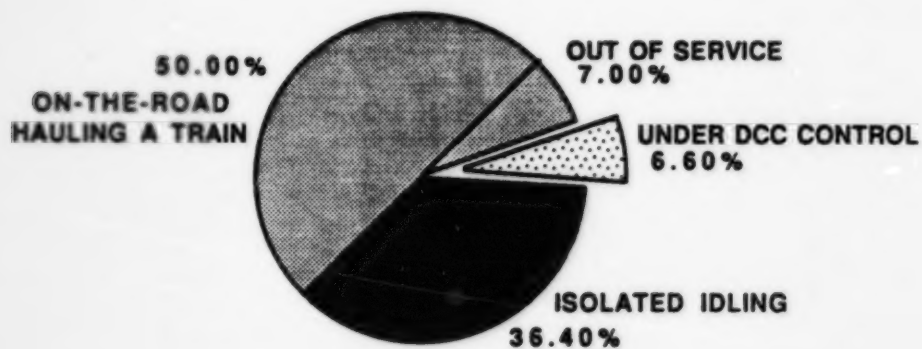
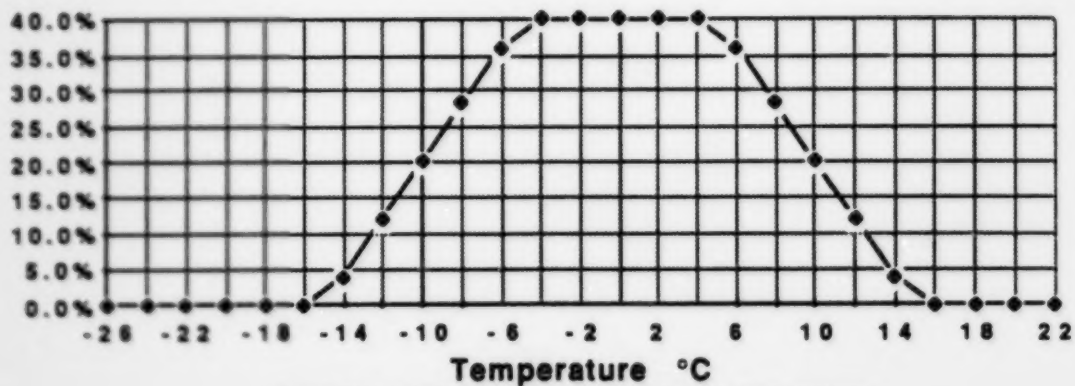


Figure 4-1

QNS&L LOCOMOTIVE UTILIZATION (OVER TEST PERIOD)



Estimated utilization based on only using the system
when ambient temperature lies between -10C and +10C

Figure 4-2

PROJECTED UTILIZATION VS MONTHLY AVERAGE TEMPERATURE

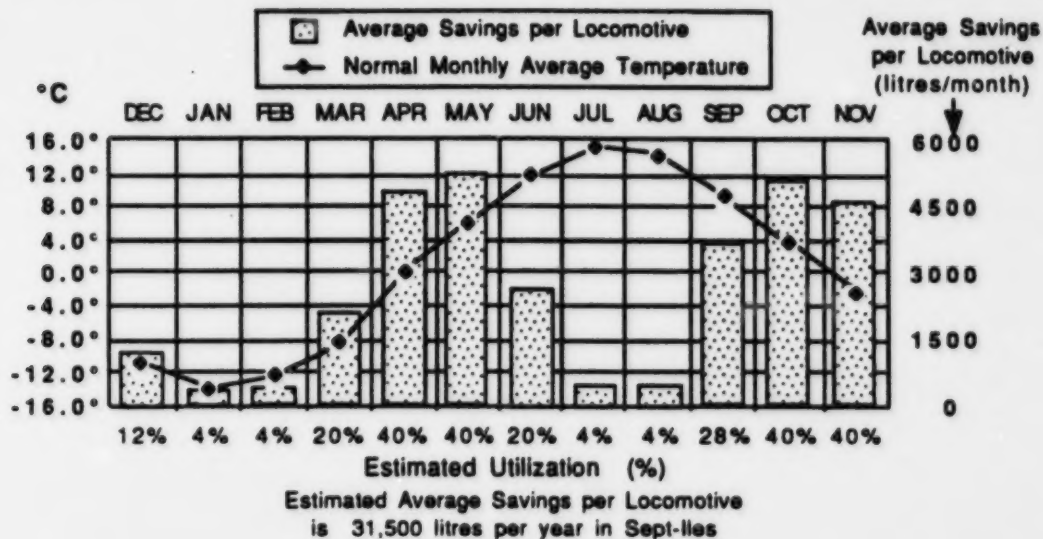


Figure 4-3

EXTRAPOLATED SAVINGS IN SEPT-ÎLES
VS NORMAL TEMPERATURE PROFILE

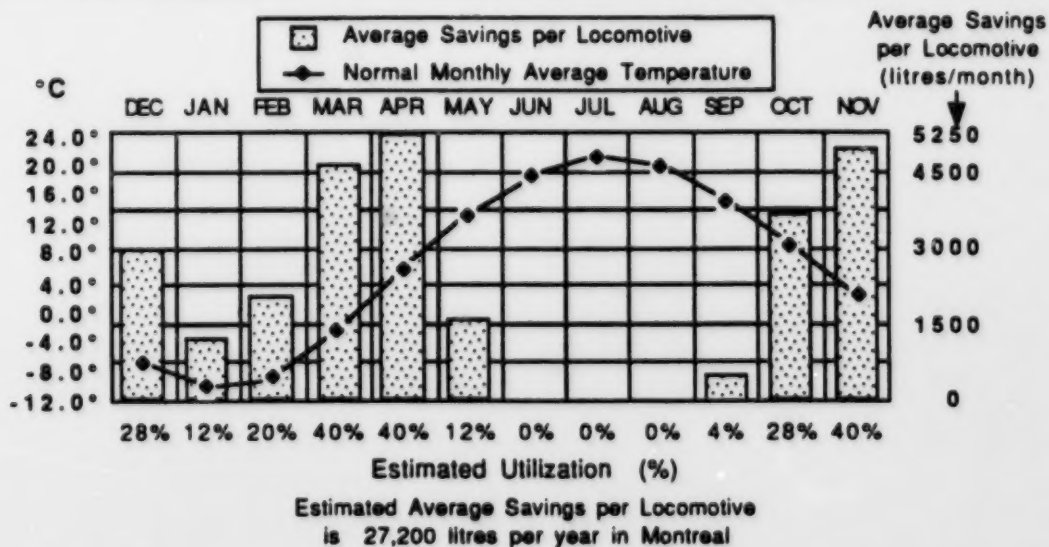


Figure 4-4

EXTRAPOLATED SAVINGS IN MONTREAL
VS NORMAL TEMPERATURE PROFILE

5. IMPROVEMENTS TO THE SYSTEM

The DCC is definitely capable of conserving significant quantities of fuel without unduly stressing the locomotive if:

- 1) it is used whenever it can be; and
- 2) it is not used outside the range of approximately -10C to +10C.

Consequently, the design of the system should be modified slightly so that it is automated as regards the following:

- 1) Locomotives are placed in Fuel Saving mode whenever they are idle. During the test, for example, this would have increased the system utilization to 43% of the time for the average locomotive were it so equipped.
- 2) Fuel Saving mode is enabled only between preset limits of ambient temperature. These limits would be adjustable; values of approximately -10C and +10C would seem to be effective.

Although these two features should be automated, override and/or configuration facilities should be included to suit local conditions or preferences.

6. CONCLUSIONS

- o A test was conducted which allowed system performance to be evaluated.
- o The quantitative measure of the system's ability to conserve fuel is termed the "Effectiveness" and is defined as follows:

$$\text{Effectiveness} = \frac{\text{Net Fuel Saved}}{F_{\text{max}}} \times 100\%$$

where:

F_{max} = amount of fuel that would have been used by the locomotive in low idle if the DCC were not in use.

This was found to be a function of ambient temperature.

- o The ability of the DCC to save fuel can be considerably enhanced by modifying the software slightly and adding a single temperature sensor. This would cause idle locomotives to automatically go into Fuel Saving mode if the ambient temperature is between prescribed limits (-10C to +10C).
- o Projections of expected annual savings were made on the basis of the Effectiveness vs. temperature relationship determined from the test, and on the basis of climatic data for both Sept-Iles and Montreal.
- o The method and rationale for predicting savings is given in Chapters 3 and 4. The process can be repeated for other assumptions and limits such as:
 - > Use of the system in a different temperature range than that assumed (-10C to +10C);
 - > Locomotives which have a different rate of fuel consumption while idling; and
 - > Climatic conditions which differ from those referenced.
- o In spite of quite different temperature distributions in Sept-Iles and in Montreal, the predicted annual savings were similar for the two locations.
- o A conservative estimate of savings in the Canadian climate is approximately 29,000 litres per year per locomotive. In the case of one major Canadian railway, this would correspond to a reduction of 4% in fuel costs.

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APPENDIX 1
Sample Log Sheet with Key

FUEL SAVING STATISTICS LOG SHEET												
TRAIN NO. (*)						LOCOMOTIVE NO.						
MILEAGE:						MASTER	TRAIL 1	TRAIL 2	TRAIL 3			
DATE:						TIME:						
NO. OF CARS:				EMPTY:				LOADED:				
DATA EXTRACTED FROM THE FUEL SAVING SYSTEM LOG												
<1> T-LOG	<2> T-F/S	<3> T-STP	<4> #-AST	<5> T-LDF	<6> T-TRF	<7> T-IUF	<8> T-ISY	<9> T-IDL	<10> T-TH4	<11> #CBST	<12> #DRST	<13> #LOST
OUTSIDE TEMPERATURE:				(Celsius)		WEATHER CONDITIONS:						
COMMENTS:												
(*) FL - QNS & L ORE, A - WABUSH, FCN, - QNS & L FREIGHT, X - EXPRESS												

LOG SHEET HEADING DEFINITIONS

All times are in minutes.

1. Total logging time (T-LOG) - time since Power-up, that the LOCOMOTIVE STATUS Switch was NOT in NORMAL or SELF TEST position.
2. Total fuel saving time (T-F/S) - time spent in Fuel Saving mode since last Power-up.
3. Total engine stopped time (T-STP) - time, during Fuel Saving mode, that engine was stopped by the system.
4. Number of automatic starts (#-AST) - number of starts performed by the system during Fuel Saving mode.
5. Total time in LEAD F/S (T-LDF) - time that locomotive has been in LEAD Fuel Saving mode.
6. Total time in TRAIL F/S (T-TRF) - time that locomotive has been in TRAIL Fuel Saving mode.
7. Total time in INDEPENDENT F/S (T-IUF) - time that locomotive has been in INDEPENDENT UNIT Fuel Saving mode.
8. Total IDLE STEADY time (T-ISY) - time engine has been idling in "primary" Fuel Saving model.
9. Total IDLING time (T-IDL) - time that engine has been idling in "secondary" Fuel Saving mode. (i.e., Drain area still cold, but engine temperature above 130F).
10. Total THROTTLE 4 time (T-TH4) - time engine has spent in throttle 4 during Fuel Saving mode.
11. Number of Cab Starts (#CBST) - number of automatic starts performed using the Cab Start feature.
12. Number of "Drain" Starts (#DRST) - number of automatic starts initiated by Auto-Drain Temperature switch.
13. Number of Low Oil switch activations (#LOST) - number of Low Oil switch activations while in Fuel Saving mode.

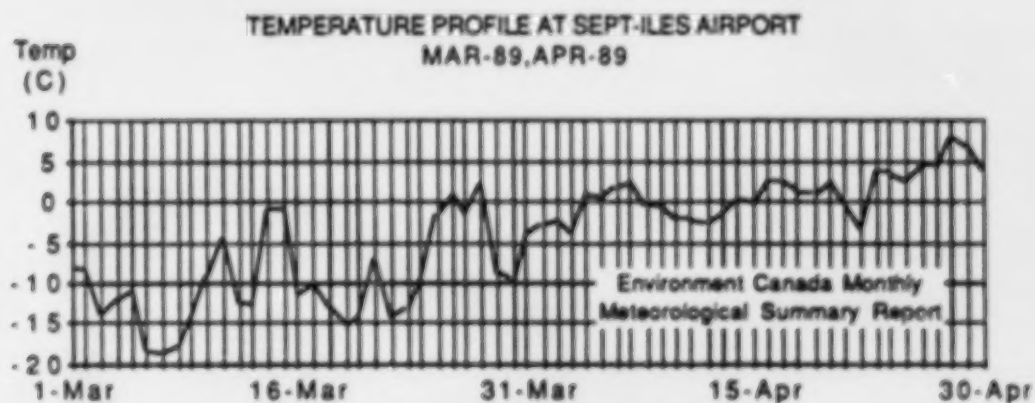
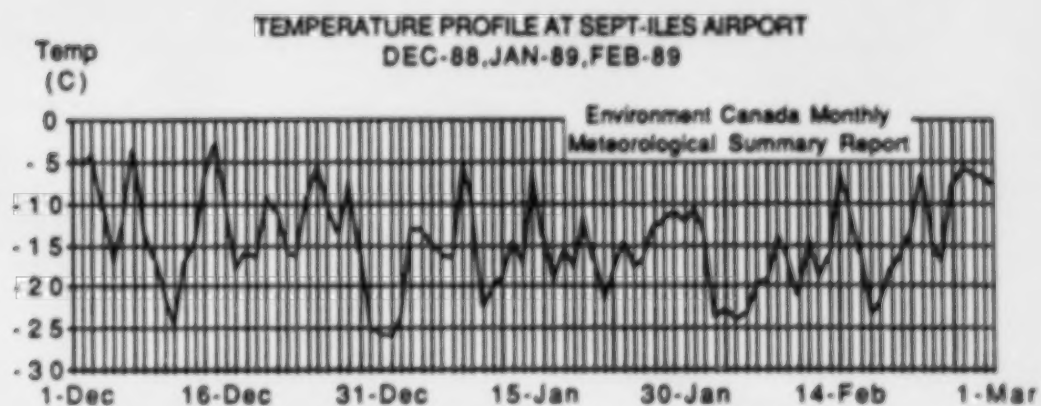
Partial Sample Spreadsheet of Raw Test Results

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	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APPENDIX 3

Temperature Profile During Test Period



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APPENDIX 4

Test Results by Locomotive

No. (-)	Locomotive Identifying No. (-)	Period Covered (days)	Time in Fuel Saving "T-FS" (days)	% Time in 120 days "%T-FS" (%)	Total Fuel Saved (litres)
1	223	127	14.3	12%	4888
2	225	128	11.9	10%	2437
3	226	10	0.8	1%	338
4	228	111	5.0	4%	1936
5	230	107	4.7	4%	1791
6	233	51	3.8	3%	1128
7	234	129	4.6	4%	1361
8	235	116	15.3	13%	5660
9	236	109	14.8	12%	5604
10	237	1	0.3	0%	103
11	238	104	2.9	2%	1133
12	239	86	5.9	5%	2296
13	240	122	6.8	6%	2932
14	242	6	1.0	1%	413
15	243	1	0.2	0%	47
16	244	80	7.5	6%	1756
17	245	75	8.1	7%	3049
18	246	127	15.2	13%	5259
19	247	109	11.3	9%	4071
20	248	101	4.9	4%	1834
21	249	45	4.2	4%	1242
22	250	64	5.0	4%	1489
23	251	113	9.0	8%	3447
24	254	78	3.9	3%	1474
25	255	99	15.5	13%	5343
26	256	105	4.9	4%	2005
27	257	128	10.0	8%	3950
28	259	122	7.7	6%	2508
29	260	129	13.3	11%	5187
30	261	95	4.7	4%	1488
31	262	127	20.8	17%	5910
32	263	115	7.8	7%	3103
33	264	131	14.5	12%	5107

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APPENDIX 3

Test Results by Ambient Temperature

Ambient Temp- erature (°C)	Time in Fuel Saving "T-FS" (hours)	Time in Throttle 4 "T-TH4" (hours)	Calculated Effec- tiveness (%)	Total Fuel Saved (litres)	Total of All Auto Starts "#-AST" (-)	Number of Drain Starts "#DRST" (-)	% Drain Starts "%DRST" (%)	Number of Engine Starts "#ENGST" (-)	% Engine Starts "%ENGST" (%)	Average Time spent warming in Throttle 4 (minutes)
-26	27.00	4.29	41%	231	14	14	100	0	0	18.40
-24	196.40	23.73	55%	2272	113	112	99	1	1	12.60
-22	224.50	25.50	56%	2733	107	107	100	0	0	14.30
-20	434.80	48.72	59%	5331	252	247	98	5	2	11.60
-18	490.25	43.49	68%	6937	223	215	96	8	4	11.70
-16	586.90	49.68	69%	8475	317	317	100	0	0	9.40
-14	879.60	79.02	67%	12356	431	419	97	12	3	11.00
-12	334.50	25.52	72%	5068	132	132	100	0	0	11.60
-10	165.40	12.47	73%	2517	88	88	100	0	0	11.00
-8	368.20	19.00	82%	6306	120	114	95	6	5	9.50
-6	354.10	28.83	70%	5205	188	188	100	0	0	9.20
-4	189.70	7.52	87%	3431	55	37	67	18	33	8.20
-2	534.30	23.89	85%	9457	128	117	91	11	9	11.20
0	900.00	25.41	91%	17124	154	123	80	31	20	9.90
2	517.80	15.43	90%	9788	89	66	74	23	26	10.40
4	354.10	17.80	82%	6103	109	71	65	38	35	9.80

Notes:

1. The total number of automatic starts (#-AST) is the sum of those due to the Drain Temperature sensor (#DRST) and those due to the Engine Temperature sensor (#ENGST).
2. "Effectiveness" is as defined in the text.

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APPENDIX 6

Projections for Sept-Iles Climatic Conditions

Month (-)	Average Normal Monthly Temperature (Sept-Iles) (°C)	Savings per Locomotive during actual test (litres)	Actual Utilization (Proportion of Total Time) (%)	Effectiveness (calculated) (%)	Projected Utilization (Proportion of Total Time) (%)	Projected Savings (i.e., at projected utilization) (litres)
DEC	-11.0°	144	1.4 %	72 %	12 %	1207
JAN	-14.0°	430	5.2 %	68 %	4 %	379
FEB	-12.5°	634	6.9 %	70 %	4 %	391
MAR	-8.6°	442	4.3 %	75 %	20 %	2104
APR	0.0°	1161	9.5 %	87 %	40 %	4864
MAY	5.9°	-	-	95 %	40 %	5315
JUN	11.7°	-	-	95 %	20 %	2659
JUL	15.2°	-	-	95 %	4 %	532
AUG	14.1°	-	-	95 %	4 %	532
SEP	9.3°	-	-	95 %	28 %	3723
OCT	3.6°	-	-	92 %	40 %	5139
NOV	-2.5°	-	-	83 %	40 %	4673

Annual Total: 31518

Note: "Effectiveness" is as defined in the text.